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Iron Depositing Bacteria and Their Geological Relations. By EDMUND CECIL HARDER. United States Geological Survey, Professional Paper 113, 1919, Government Printing Office, Washington. Pp. 85, pls. 12, figs. 13.

Geology, probably more than any other science, occupies an apical position in the pyramid of the natural sciences; its function is not so much to enunciate the more fundamental theories *not* based on the concepts of other branches of knowledge, as to weld together the contributions of its sister-sciences and apply them to its own purposes. From this point of view a work such as that under review is especially illuminating; it demonstrates conclusively the hitherto only partially appreciated breadth of scope of the "science of rocks and minerals."

The paper begins with a careful description of the living iron-depositing bacteria, both those of the higher and those of the lower type. Not only the more common forms, such as *Leptothrix*, *Galionella*, and *Spirophyllum* are mentioned, but a brief review of the classification, morphology, and physiology of essentially all relevant forms known to date is given. The iron-bearing algae also are named. From the early work of Cohn and Zopf, who thought iron accumulation in bacterial sheaths essentially a mechanical process, through that of James Campbell Brown, who considered the deposition of ferric hydroxide to be merely incidental to the extraction of the organic constituents in the water affected, to the studies of Lieske, which demonstrated conclusively that the carbonate radicle of ferrous carbonate is extracted by the bacteria, leaving the insoluble hydroxide, the increasing importance of bacterial metabolism has come to be recognized. It is probable, in fact, that some bacteria require ferrous bicarbonate; that others can use it interchangeably with other soluble iron compounds; while still others, notably the lower groups, can use only the organic salts of iron.

Mr. Harder himself prepared and studied cultures of various forms. *Crenothrix* was obtained from city water of Madison, Wisconsin, which contained large amounts of magnesium and calcium carbonates. Cultures of *Leptothrix ochracea* were grown from the water of a chalybeate spring near Madison, the water bearing much ferrous iron in solution, probably as the bicarbonate; this form was also brought up from a low level of a Cuyuna District mine, where ferric hydroxide is being precipitated in large amounts. Cultures of *Galionella ferruginea* from the Federal Mine of Wisconsin and from the Kennedy Mine of central Minnesota are also reported; in both of these localities a brown, gelatinous scum occurs on the walls of the tunnels and in little pools in the drift-floors. *Spirophyllum ferrugineum* appears in the waters of the

Wisconsin zinc mines; it was also found in other mine-waters, probably being carried downward by surface waters that descended through the soil and rock for many hundreds of feet. The form is especially abundant in the water of Vermilion Lake, Soudan, Minnesota. All these bacteria precipitated ferric hydroxide.

Besides these there are other iron bacteria which precipitate ferric hydroxide or ferrous sulphide. The former group is especially widespread, and though its members do not require iron in solution for their development, still it is thrown down quite rapidly as a waste product. The precipitating action of such forms was studied by means of weak solutions of the slightly acid ferrous ammonium sulphate.

Whereas some of the sulphide-precipitating bacteria owe this ability to the action of the hydrogen sulphide liberated by them on the ferric salt in solution, others precipitate the sulphide because of their reducing action on the sulphate. When water bearing ferric ammonium citrate was inoculated with hay and soil infusions, there resulted a precipitation of ferric hydroxide not observed in the sterile solution. This ensues even under anerobic conditions. The organisms that induced it were grown on plates of Heyden Naehrstoff agar with ferric ammonium citrate as indicator and various types of bacteria were recognized. Slopes of Heyden agar to which no citrate was added showed practically no growth. Other organic salts of iron were also used more or less successfully, and similar experiments showed that no precipitations resulted from the solutions bearing salts of manganese in place of iron.

On the other hand, no precipitation that could be definitely assigned to organic processes could be obtained from inorganic iron salts such as the bivalent carbonate or sulphate or ferric chloride, the precipitation that *did* result in these cases being better attributed to the purely inorganic oxidation and (or) hydrolysis. These results do not agree with those of Mumford (*Chem. Soc. Jour.*, Vol. 103, 1913).

A review of the earlier work of Beijerinck, Van Delden, and Fred on the formation of hydrogen sulphide by bacteria may be summarized as follows: sulphates are formed abundantly by sulphur bacteria from hydrogen sulphide; these sulphates are then reduced by other bacteria to yield sulphides and hydrogen sulphide; if ferrous or manganese sulphides are formed they are precipitated. These observations have been ably and fully discussed in other papers, notably in their bearing on the origin of the Sicilian sulphur deposits.

The relations of these facts to geologic processes are amplified by the writer. He points out the solubility of iron carbonate; soluble organic compounds, chiefly humides, of iron may also be formed; it is

these that lend the dark color to streams flowing through regions of abundant vegetation. Finally, a smaller amount of iron may be carried as sulphate.

Iron deposits occur in the form of hydroxides and oxides, carbonates, and silicates. Iron is readily precipitated as the hydroxide, when a solution containing an excess of carbon dioxide is induced, through changes in pressure or temperature, to give up its gas with a concomitant saturation with oxygen; if the solution merely loses its carbon dioxide without undue oxidation, ferrous carbonate tends to be precipitated. These several iron precipitates generally accumulate in bogs, lakes, or lagoons. Elsewhere rapidly flowing waters may (rarely) form iron deposits.

Most deposits of bedded hematite, bog ore, and brown iron ore were laid down originally as hydroxides, chiefly through biologic, but also in part through chemical, agencies. Iron sulphide, too, may be formed in either way, but ferrous carbonates and silicates are not definitely traceable to bacterial action. Iron phosphates and basic ferric sulphates are chemical precipitates. Ferrous silicates tend to be deposited where alkaline silicates are abundant in regions of precipitation of ferrous carbonates—formed as indicated above. Probably 90 per cent of all the iron ores being worked today are of the sedimentary type. A list and description of those thought to be originally laid down as ferric hydroxide includes the Clinton ores, the Wabana ores, the Lake Superior hematite-chamosites, the itabirites of Minas Geraes, (Brazil) the hematite-magnetites of the Dharwar terrain of India, and the ores of the Norwegian Lias. Bog iron ores, too, were probably deposited in the same form and are now widely distributed, being especially abundant in the eastern part of Canada and the United States, in Sweden, and in the glaciated sections of Europe and Asia; ferric hydroxide is also present in large amounts in the red mud off the coast of Brazil.

Another type of sedimentary iron ore is that originally deposited as the carbonate; this is represented by the "black band" ores in Ohio, Pennsylvania, and West Virginia, the oölitic siderites of eastern England, and the siderites of the Lake Superior region.

The silicates present a third type of sedimentary iron ore. The forms in which the iron occurs include glauconite, bavalite, thuringite, bertherine, and chamosite; of these glauconite is the most widespread. Greenalite was probably the original constituent of the Mesabi ores, while the chamosite ores are predominant in the Bohemian Brdagebirge.

Ferric and ferrous sulphides represent the fourth type of iron deposits. Pyrite is important in the Huelva region of southern Spain, in the

Carpathian and Harz Mountains, and in Westphalia; the sedimentary origin of some of these beds, however, is still in doubt; more typically sedimentary are some of the oölitic pyrite beds of Wabana. Ferrous sulphide is common in the limans of the Black Sea. The general explanation offered for these deposits is that of Doss, who believed that the iron is carried as a carbonate, upon which bacteria may act directly or indirectly to yield colloidal ferrous sulphide or ferric hydroxide, which in turn is converted into ferrous sulphide.

Various facts of importance to students of sedimentation are brought out in a discussion of the origin of the separate iron deposits; for instance, the experiments by Spring and Ruff on the conditions favoring and opposing the derivation of limonite from ferric hydroxide. It is shown, also, that primary deposits of ferric hydroxide may be readily altered to the carbonate, especially in the presence of large amounts of organic matter.

From a discussion of the inorganic causes for the precipitation of iron compounds as sediments, the writer returns to a consideration of organic causes. Here, especially in connection with the precipitation of ferric hydroxides, the line is not readily drawn between oxidation, taken as the purely inorganic process, and bacterial action; the latter, however, is surely of much importance, whether actually preponderant or not. The conditions under which iron-bearing bacteria are active vary between wide limits. Temperature, if too high or too low, may be inhibitory, as may also be a reduction in the amount of organic matter present.

To present in detail all the significant facts of this interesting paper, would necessitate a review as long as the original publication; it must be read to be fully appreciated. It displays both the clear thought and the technical skill of Mr. Harder in original work and his ability to join his observations to those of other investigators of the subject. All in all, it is a most admirable contribution to experimental geology.

C. H. B., JR.

Helium-Bearing Natural Gas. By G. SHERBURNE ROGERS. United States Geological Survey, Professional Paper 121. Washington, 1921.

This report comes from the press many months after the accidental death of its author in South America. It reflects so zealous a spirit of scientific research in the public service that it stirs anew the sorrow of